IMPROVED METHODS OF FORMING A SPLINED SHAFT

Cross Reference to Related Application

[0001] This application is a Continuation-in-Part application of U.S. Serial No. 10/772,733 filed on February 4, 2004 (Docket No. 02-3680), entitled "Method of Forming A Splined Shaft" which claims priority under 35 U.S.C. 119 based on U.S. Provisional Application No. 60/449,523 filed February 21, 2003.

Technical Field

[0002] The present invention relates to methods and apparatus for forming splined shafts. More particularly, the method and apparatus of the present invention as it relates to the forming of splines in shafts and tubes from aluminum alloys.

Background Art

[0003] The pressure "forming" of a metallic material/metal into a desired shape, by hydroforming/explosion forming; electromagnetic forming ("EMF"); rolling; stamping; drawing; swaging; and the like ("forming"), is known in the art. With some metallic materials, such an operation often times disrupts the structural integrity of the metallic material. Indeed, many metals and alloys have unstable tempers, which do not lend themselves to downstream permanent deformation via forming (as defined above). Thus, it has been standard practice to use only metals of certain stable tempers for such operations. Patents in this area include U.S. Patent Specification Nos. 4,766,664; 5,363,628; 5,720,511 and 5,911,844 (Benedyk, Basar et al., Benedyk and Benedyk respectively).

[0004] For instance, in the sheet metal industry, stable, age hardened materials (such as alloys with stabilized -T4 tempers) or fully annealed materials are used in order to achieve maximum formability in stamping or drawing operations. While such materials have been useful, in many applications it is desirous to use an even harder alloy, such as an aluminum alloy having -T6 temper properties.

[0005] In particular, unsatisfactory results have been observed with the forming of

many types of aluminum alloys (not to mention other metallic materials). For example, a -T4 temper aluminum alloy material is desirable from a ductility and strength standpoint for use in stamping operations. One such advantage is that it does not need to be solution annealed in order to be able to approach stronger -T6 temper properties in the finished components. The -T4 temper materials need only be aged at moderate temperatures for short periods of time to achieve near or full -T6 temper properties. However, there are drawbacks to using an unstable -T4 temper material in stamping operations inasmuch as the -T4 temper is long-term unstable. Due to its instability, if a -T4 temper material is used to make a component (through a forming process) the drawn/stamped region can develop cracks during the forming operation. And as such, the component is defective and unusable. But, if readily formable, it would be desirous for use in many applications.

[0006] On the other hand, a -T5 or a -T6 temper aluminum alloy is stable. However, it is difficult to draw or stamp such a material. Indeed, the material is generally too brittle to permit forming through such processes. As such, if any forming is attempted with such a material, the material quickly deteriorates and cracks develop. Thus, this material is likewise unsuitable for any such processes.

[0007] It is thus an object of the present invention to provide a method for deforming via forming hard metallic materials that have been conventionally deemed unacceptable for such stamping or drawing.

[0008] It is also an object of the present invention to deform (forming) such metallic materials at predetermined regions, wherein the predetermined regions have stretched (or drawn) areas having depths greater than conventionally obtainable--without the formation of any visually observable cracking in the formed areas.

[0009] These and other objects and advantages of the present invention will be more fully understood and appreciated with reference to the following description.

Summary of the Invention

[0010] The present invention is a method for forming splines on a metallic tube, comprising the steps of: (a) providing a metallic tube having a known hardness properties

approaching or corresponding to T4 temper; (b) heating the metallic tube to a temperature sufficient to remove the T4 temper; (c) quenching the metallic tube; (d) forming splines on the metallic tube; and (e) artificially or naturally aging the metallic tube. Preferably the metallic tube is a 6000 series aluminum alloy, but can include any heat treatable alloy. Quenching in step (c) should immediately follow step (b) which involves a retrogressive heat treating cell, which is the heart of this embodiment of the invention. T4 temper, as well as other temper designations, is defined as solution heat-treated and naturally aged to a substantially stable condition. Aluminum Standards and Data 1979, The Aluminum Association p.11-14, herein incorporated by reference.

[0011] The invention provides a method for preparing aluminum tubing for forming of a spline geometry for engaging lightweight and simple telescoping aluminum tubes for assembly into torsionally rigid automotive drive shafts and steering shafts with axial compliance. The geometry of the required splines is beyond the forming limits of 6000 (6XXX) series aluminum alloy tubing in the –T4 and –T6 tempers.

[0012] A general inductive heat-treating process for aluminum, known as RHT (retrogressive heat treatment) has been useful for mechanical/compression joining of hollow structural members.

[0013] In contrast, the process of the present invention provides a method of enabling the forming of a complex geometry in telescoping, round aluminum tubular members to precise matching tolerances. The steps include:

(a) providing a drawn or extruded, seamless or non seamless 6000 (6XXX) series type aluminum alloy tube in the –T4 or –T6 temper,

(b) rapidly heating that tube to temperature of 650°F to 1000°F (343°C -538°C) preferably about 900°F to 1000°F (482°C-538°C) using an AC electrical induction coil that covers from only a section to 95% of the length of the tube while maintaining the tube in a stationary position or rotating it while the tube is in an axis vertical position and/or including an axial oscolation of the tube in the induction field.

(c) quenching the heated tube in water, air, gaseous quenchants or other suitable quenchant, such as a polymer based glycol solution or quenching, to temperatures approaching and to room temperature (about 23 °C), in a gaseous water solution whereby the metal condition/temper after quench is now –W, a state that affords high ductility with low yield strength (a highly formable condition),

(d) optionally rinsing the tube,

(e) optionally drying the tube, and

(f) subsequently forming circumferentially applied axial splines along a portion of the tube's(s) length.

The heating may be at only two or more sections of the tube with a non-heated section between them. The quenching may be by immersion, spray or mist quenching. It can be in a tank having a temperature less than about 212°F (100°C). Preferably the splines are formed within 16 hours of quenching if the tubes are stored at room temperature, most preferably within 8 hours of quenching. The quenched metallic tube can be cooled to below room temperature to retard natural aging. If artificially aged, the tube can be heated to at least 300°F (149°C) for at least 4 hours.

[0014] The invention also includes a simplified method for forming splines on a metallic tube, comprising the steps of: (a) forming a metallic tube; (b) solution heat treating the metallic tube; (c) controlling time and/or temperature exposure conditions of said metallic tube so that a T4 temper is not achieved; (d) forming splines on said metallic tube before said metallic tube has aged sufficiently to develop properties corresponding to a T4 temper; and (e) aging said metallic tube. Preferably, the splines are created within 16 hours of forming said metallic tubes. In a preferred embodiment, the metallic tube is a 6000 series aluminum alloy.

[0015] The present invention permits rapid manufacturing of lightweight aluminum telescoping tubes containing rigid, engaging precise splines. Tolerances of +/-0.001 inches or better can be achieved using the present invention.

Brief Description of the Drawings

[0016] Other features of the present invention will be further described in the following related description of the preferred embodiment which is to be considered together with the accompanying drawings wherein like figures refer to like parts and further wherein:

[0017] Figure 1 is a flow chart illustrating the major steps in the fabrication of formed metallic tubes in accordance with one embodiment of the present invention using RHT;

[0018] Figure 2 is an illustration of process steps of induction heating using RHT, quenching, and aging metallic tubes in accordance with the present invention;

[0019] Figure 3 is a flow chart illustrating the major steps in the fabrication of formed metallic tubes in accordance with a simplified embodiment of the present invention not using RHT;

[0020] Figure 4 is an illustration of a drive shaft, showing the splines; and

[0021] Figure 5 is a cross section view of a splined metallic tube formed in accordance with the present invention.

Mode for Carrying Out the Invention

[0022] The invention, in one embodiment (RHT), provides a method of rapidly resolution heat-treating 6000-T4 and –T6 aluminum alloy tubing without adversely affecting the grain structure or ability of the material to ultimately achieve its optimum strength for service. Immediately after application of the process the material is in very ductile state (W temper) in which extensive and precise mechanical forming, i.e., spline forming, can be easily accomplished without fear of cracking, tearing, or undesirable surface roughening of tubing. The resulting matching splines possess a smooth and crack free surface of uniform properties necessary for application of a wear resistant coating of a controlled thickness needed for service use.

[0023] The invention provides a method for preparing aluminum tubing for forming of a spline geometry for engaging lightweight and simple telescoping aluminum

tubes for assembly into torsionally rigid automotive drive shafts and steering shafts with axial compliance. The geometry of the required splines is beyond the forming limits of 6000 aluminum alloy tubing in the –T4 and –T6 tempers.

[0024] As Shown in Fig. 1, incoming stock 10 of a heat treatable alloy of or approaching T4 temper, straight or swaged, seamless or non-seamless aluminum tubing is passed to a retrogressive heat treating (RHT) cell 12, an appropriately sized induction coil connected to an RF AC generator, where it passes through a heating phase 14. The incoming stock requires no particular storage or treatment. In the heating phase, which is very important and required, the induction coil is energized and temperature monitored via thermocouples, infrared devices or temperature sensitive coating. Fig. 2 also shows the induction-heating step 14 where induction coil 16 surrounds the incoming stock 10 and heat, shown by arrows 18, is passed to the stock 10. Then the incoming stock is passed to a required quenching stage 20, to undergo vertical or horizontal quenching via air, water, air and water or by other type quenching, also shown in Fig. 2 where water 22 is used to release heat shown by arrows 24. Then the quenched stock is passed to an optional rinse phase 26 and then to an optional air or low heat-drying phase 27. Power lines to the RF power supply are shown as 40.

[0025] Splines, shown as 28 in Figs. 4 and 5 are formed in step 30 by rolling, drawing or stamping. Here the stock is immediately inserted over a mandrel and axially or circumferentially deformed over a prescribed engagement length to form splines. This is followed by naturally or artificially aging, preferably artificially aging to a full hard condition, usually T6, in step 32. Applied heat is shown in Fig. 2 as arrows 34.

[0026] Turning first to Fig. 3, there is a flow chart illustrating the major steps in the fabrication of formed metallic tubes in accordance with a simplified, non-RHT embodiment of the present invention. This process is very more cost effective, eliminating some steps of the previously discussed embodiment and provides less distortion, and therefore, improved product quality.

[0027] The first step 50 is to take incoming stock (non-solution heat treated) which may be a formed straight or swaged, seamless or non-seamless metallic tube, which has been heat treated prior to solution heat treating in step 52. The forming may be from an elongated sheet product that is rolled in a circular configuration and then welded to form a tube. The forming method used to make the tube is not critical to practicing the invention.

[0028] The second step 52 is to solution heat treat the newly formed tube by direct quenching from a hot working process or by separate solution heat-treating and then control the time and temperature exposure of the newly quenched tube by controlled cooling of the metallic tube to room temperature (around 16°C to 30°C) and/or cooling the tube well below room temperature, preferably at least 5°C to 15°C below room temperature and maintaining these conditions of exposure to retard natural aging and so that a T4 temper is not achieved and accommodate the further processing of the tube. A post heat treating process 53, such as straightening, machining or the like can also be utilized. All this involves controlling the time and or temperature exposure conditions so that a T4 temper is not achieved showed by dotted enclosing lines, step 54 and by step 55.

[0029] The next step 55 is to form the splines on the metallic tube, the previously defined "forming" process. If the metallic tube is being stored at room temperature, the process of forming the splines, preferably, must occur within twelve hours after the metallic tube is cooled to room temperature, preferably within about 8 hours. The natural aging process can be delayed indefinitely if the tube is brought to a very low temperature. Liquid nitrogen, carbon dioxide or refrigeration equipment can be used to bring the temperature to –10°F (-23.3°C) or lower to delay or stall the natural aging process. The splines can be formed by a cold forming process.

[0030] The next step 56 is to naturally age it to a full/stable T4 condition or artificially age it to a full/stable T6 condition, preferably at least 300°F (149°C) for about 4 hours.

[0031] After the metallic tube has been artificially aged, an optional step 58 is to harden the splines by using an anodizing process.

[0032] Turning next to Fig. 4, where the fugure shows a drive shaft 60 with a diameter having splines 28 at a splined end. The splined end has a length 64. The splines 28 are more clearly visible in Fig.5.

[0033] In the preferred embodiment of the invention, the members are manufactured from conventional and commercially available lightweight aluminum material which may comprise a commercially available 6061-type of aluminum alloy material. The splines are "cold formed" upon the portions by the use of a conventional processes. Splined portions can then optionally be selectively hardened or "anodized" in accordance with most commercially available anodizing processes. More particularly, the splined portions, in one non-limiting embodiment, are anodized with a layer of "hard coat" material having a thickness of about 0.002". (0.005cm)

[0034] Importantly, the use of such anodized aluminum and cold-formed spline portions allows for a relatively lightweight drive shaft which substantially reduces the amount of vibration and noise which emanates from the operatively formed drive shaft. The relatively lightweight aluminum construction allows the drive shaft to have relatively large diameters, while providing a significant decrease in the overall weight relative to prior drive shafts. These relatively large diameter members efficiently distribute the applied axial and torsion loads over a larger surface area, thereby allowing the drive shaft to support relatively larger torques at relatively higher speeds than prior drive shaft assemblies. Further, this relatively lightweight design allows for relatively long spline portions. In other alternate non-limiting embodiments, splines have lengths which respectively extend approximately half way along members or have respective lengths equal to approximately three times their respective diameter. The anodized aluminum splines also allow for a relatively large and/or wide splined mating surfaces and/or "working areas" (e.g., which in one non-limiting embodiment have a "radial load surface length" equal to about 3 to about 4 millimeters). These wide splines allow for better

distribution of the axial loads imparted upon portions effective to reduce the overall wear of the splines and the "working" or "operating" life of the drive shaft 10. The splines also allow for length variation in the shaft due to in-service conditions and crash management. It further allows for the improved redesign of tube end connections (yokes, universal joints, etc.) to enhance reliability and performance.

[0035] In one non-limiting embodiment, each end wall of each spline cooperatively forms an angle of about 60°, although other angular configurations may be utilized. Further, it should be appreciated that these relatively long intermeshing portions reduce the amount of noise and/or vibrations which are generated from the drive shaft and these relatively long splined portions reduce the probability that the drive shaft will undesirably buckle in a collision, thereby increasing the overall safety of the vehicle. Further, these relatively lightweight members having relatively long respective splined portions allow for the creation of a relative stiff and lightweight driveshaft.

[0036] The present invention may be more clearly understood with reference to the following examples.

<u>RHT Example 1</u>

[0037] A cracking problem existed when "forming"-as previously defined as one of hydroforming/explosion forming; electromagnetic forming (EMF); rolling; stamping; drawing; swaging and the like- splines in 6061-T4 tube. Tube diameters involved were 3 ½ and 5 inches in diameter. An RHT treatment was applied to the tubes to achieve local softening and improved formability in the region used to form the splines. Surprisingly, the RHT process permitted 6061and 6013 to be formed, through the standard processing of the spline-rolling machine.

[0038] It is preferable that the metallic tube is an aluminum alloy of the 2000, 6000 or 7000 series as set forth in <u>Aluminum Standards and Data 1979</u>, The Aluminum Association, pp. 13-14. Most preferably the metallic tube is formed from a 6000 or 7000 series alloy from the group consisting of 6013, 6061, 6063, 7003, 7029 and 7108 as described in <u>International Alloy Designations and Chemical Composition Limits for</u>

Wrought Aluminum and Wrought Aluminum Alloys, The Aluminum Association, pp 1-10, October 2002, herein incorporated by reference.

[0039] The metallic tube may be a seamless or non-seamless extrusion, a drawn seamless tube or a tube formed from an elongated sheet product that is rolled in a circular configuration or welded to form a tube. In addition, the metallic tube may be swaged or double swaged to form a tube of multiple diameters and thicknesses.

Non RHT Comparative Example 2

[0040] A number of 3 1/2 inch diameter tubes of aluminum alloy 6013 having an unstable T4 temper were formed and stored at room temperature for approximately two weeks. After this two-week period during which natural aging occurred, splines were rolled into the aluminum tubes. The splines were "cold formed" into the tubes by using a conventional process which involves the use of commercial equipment provided by Ernst Grob AG of Mannedorf, Switzerland.

[0041] Some of the splines in the 6013 tubes, however, cracked during roll forming.

Non RHT Example 3

[0042] Again, 3½" diameter tubes of aluminum alloy 6013 having an unstable T4 temper were formed as in Example 2. In contrast to Example 2, the aluminum tubes were maintained at room temperature for less than 12 hours before the splines were roll formed into the tubes.

[0043] The tubes did not crack. Without wishing to be bound by any theory, it is believed that the two-week period of natural age hardening that occurred before the tubes in comparative Example 2 underwent the Grob equipment processing decreased the formability of the tubes. This is surprising because the tubes have not finished natural aging.

[0044] In contrast, the aluminum tubes in Example 3 underwent the "forming" process before the tubes experienced any significant natural aging. The heart of the invention is to control the time and temperature exposure of metallic tubes to allow for

successful processing (forming) of splines into the tubes before the metallic tube has aged sufficiently to develop properties of lower ductility which are present when approaching a T4 temper.

[0045] It is preferable that the metallic tube is an aluminum alloy of the 2000, 6000 or 7000 series as set forth in Aluminum Standards and Data 1979. Most preferably the metallic tube is formed from a 6000 series alloy from the group including but not limited to 6013, 6061 and 6063. The metallic tube may be a seamless or non-seamless extrusion, a drawn seamless tube or a tube formed from an elongated sheet product that is rolled in a circular configuration and then welded to form a tube. In addition, the metallic tube may be swaged or double swaged to form a tube of multiple diameters and thicknesses.

[0046] Even though the invention was disclosed using a "Grob" equipment, other splining methods known to the art are also covered within the scope of the invention.

[0047] What is believed to be the best mode of the invention has been described above. However, it will be apparent to those skilled in the art that numerous variations of the type described could be made to the present invention without departing from the spirit of the invention. The scope of the present invention is defined by the broad general meaning of the above description.